OBSERVATIONS OF THE SUBAURORAL NON–THERMAL RADIO EMISSION (SANE) IN 1995–1998

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Abstract

The results of about four years continuous observations of the subauroral non–thermal radio emission (SANE) on board of the INTERBALL–1 satellite are presented. This unexpected high frequency terrestrial radio emission was discovered in 1985 (at the minimum of solar activity) by the experiment on board of the Prognoz–10 satellite at 1486 kHz. In an AKR–X experiment on board of the INTERBALL–1 satellite reported here this emission was observed at the frequency 1463 kHz beginning from August 1995 (at the minimum of solar activity) until the end of 1998 when it gradually disappeared with the increase of the solar activity. Close to the maximum of solar activity (in 1999–2000) SANE events were not registered. The main peculiarities of the SANE (the intensity and character of the signal, the appearance in time, beaming and direction of the distant passage) are presented and discussed.

1 Introduction

As a result of experiments on board of satellites we know at present several different magnetospheric radio emissions which are the important indicators of the magnetized plasma state. The investigation of non–thermal so–called "continuum" emissions (terrestrial continuum at frequencies below 100 kHz was first discovered by Brown [1973]) is of special interest, since as a widely spread planetary emission the mechanisms of origin are still not clear today.

The radio emission of the terrestrial inner magnetosphere at the frequency 1486 kHz, discoverd by the Prognoz–10 satellite in 1985 [Kuril'chik et al., 1988; Kuril'chik et al., 1992a,b,c], were observed for four years (1995–1998) by the INTERBALL–1 satellite at frequencies of 1463 and 1501 kHz. This SubAuroral Non–thermal Emission (SANE) is generated inside the plasmasphere very close to the earth's surface next to or in the mid–latitudinal ionospheric trough. It has a pronounced character of sharp beamed radio emission, primary impulsive structure and remarkable effect of an intensity "saturation". Some preliminary results of SANE investigation were published in Kuril'chik et al. [1997].

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2 Observations

The INTERBALL–1 satellite was launched on August 3, 1995, into a highly extended elliptic orbit with an apogee of 32 R_E (40°N) , and operated till October 16, 2000. The observations of SANE reported here were taken by the spectrum analyzer AKR–X with a trapezoidal frame antenna which received only electromagnetic emissions. Six fixed frequency channels were used (100, 252, 500, 749, 1463 and 1501 kHz) with a bandwidth of 10 kHz (dynamical range of about 80 dB, registration of emissions every 1 or 2 s).

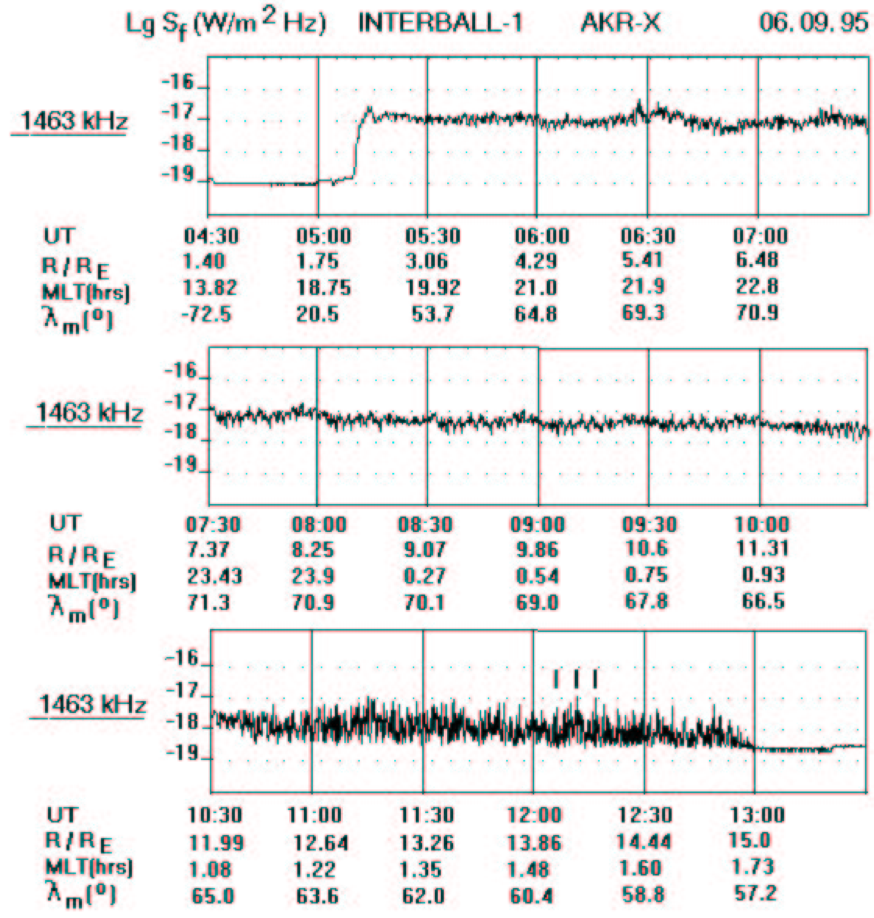

Figure 1: Unique long time registration of SANE at September 6, 1995. MLT and λ_m correspond to the magnetic local time and the geomagnetic latitude, respectively. After passage of the plasmasphere the INT–1 satellite was about 8 hours in a favorable position to observe this emission.

The AKR–X experiment was devoted to a continuous monitoring of cosmic radio emissions. SANE was observed predominantly at a frequency of 1463 kHz, where the influences from on board devices were minimal (background level was about 10^{-19} W m^{-2} Hz^{-1} which is equal to the galaxy background [Gurnett, 1975]). The channel 1501 kHz was steadily influenced by the interferences and only rare powerful SANE events were registered.

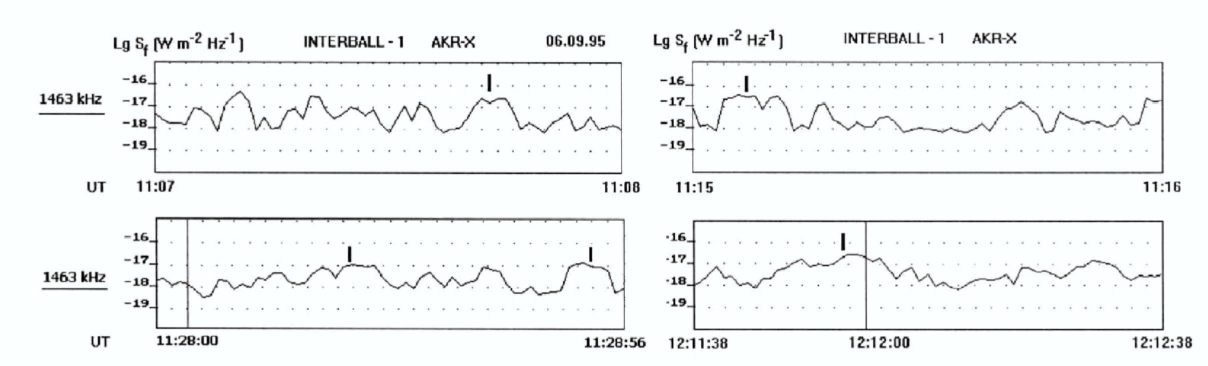

Figure 2: Several large impulses registered after 11:00 UT (marked by short lines in Figure 1) with the time resolution 1 s. The impulses show flattened tops at the level of the flux density of SANE background saturation.

An example of SANE registration is shown in Figure 1. It demonstrates all main peculiarities of the signal, such as "saturation" at the level about $(2-3)\cdot10^{-17}$ W m^{-2} Hz^{-1} flux density at the beginning of registration, very slow decrease of the flux with the increase of distance (because of the beamed character of emission), a transition at the end of registration to an impulsive structure of the signal, which is typical for the majority of SANE events.

Figure 2 shows several large pulses registered after 11:00 UT (marked by short lines in Figure 1) with the time resolution of 1 s. (Figure 1 has 10 s averaged time resolution.) These pulses have flattened tops over about 4–8 s at a flux level of approximately $(2-3)\cdot10^{-17}$ W m^{-2} Hz^{-1}, which is the "saturation" level of the flux observed close to Earth (close to the source of emission).

Figure 3a-b shows segments of the INT–1 satellite trajectories (distance R/R$_E$ versus geomagnetic latitude λ_m) along which SANE events have been continuously recorded in the Northern Hemisphere at the first annual period of observations (August 1995–July 1996). The main bulk of events is observed below the Northern auroral region, at Northern subauroral latitudes. These events are characterized by larger intensity and longer duration in time because of the slow change, respectively decrease in latitude of the satellite. Figure 3a corresponds to SANE events associated with time intervals between 04 and 13 hours UT, Figure 3b - between 18 and 01 UT (see below the distribution of events as a function of UT). SANE events were observed close to and far away from the Earth till the apogees in the range 19 - 08 MLT at 55 orbits. When the apogees were in the range 09 - 20 MLT (day–side, February 1996–July 1996, and 40 orbits out of 95 per year) SANE was observed only close to the perigees in the night–side sector, and also in the interval 19 - 08 MLT.

According to Figures 3a and 3b the SANE beams have different widths along geomagnetic latitude. Largest beam widths were observed at around 60° geomagnetic latitude, i.e. beams which are emanating out of the night mid–latitudinal ionospheric trough. It has been supposed that the emission enters the trough from the denser region of the

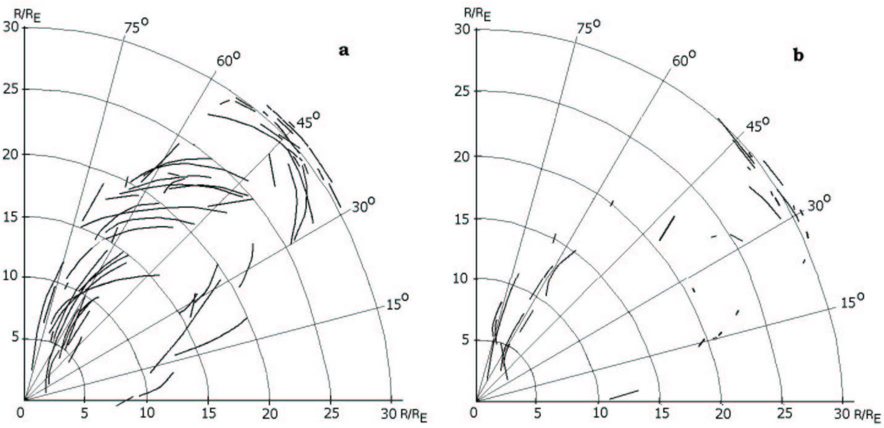

Figure 3: The registration of SANE during 55 orbits of the satellite with apogees between 19 and 08 hours LT (night side): (a) observations registration between 04 and 13 UT, (b) observations between 18 and 01 UT.

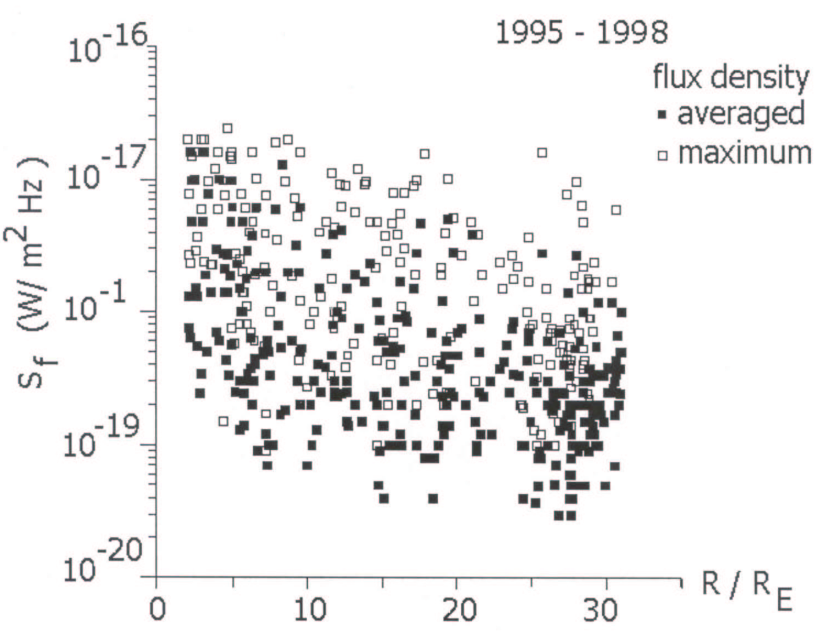

Figure 4: The averaged and maximum flux density of SANE as a function of the geocentric distance.

plasmasphere through a "window" in the density gradient of the equatorial wall of this trough [Kuril'chik et al., 1992c]. The average latitudinal width of the beams observed around 60° until a distance of 25 R$_E$ from the Earth is $12° \pm 8°$. This is in agreement with estimations of the width of the night winter ionospheric trough from plasma density measurements [Ershova and Sivtseva, 1989].

Contrary to Figure 3a, the segments of the orbits in Figure 3b often show very narrow beams (1°–3°) along the geomagnetic latitude. These beams, as a rule, have an impulsive structure, their latitudinal positions change from one orbit to the other. Figure 4 shows the averaged and maximum (impulsive part) SANE flux density versus distance R/R_E from the Earth for all observed events in 1995–1998. From the geocentric distance $R/R_E = 2$ to $R/R_E = 32$ the observed flux densities S_f (both average and maximum) gradually decrease in median from $(3 \div 5)\cdot 10^{-18}$ W m^{-2} Hz^{-1} to $(3 \div 5)\cdot 10^{-19}$ W m^{-2} Hz^{-1}. The maximum S_f gradually changes from about $2\cdot 10^{-17}$ W m^{-2} Hz^{-1} to $2\cdot 10^{-18}$ W m^{-2} Hz^{-1}.

This means that the median beaming gain (in comparison with an isotropic radiating source) is about 100 (distance squared as about 10^3, however flux densities decrease about factor 1/10). The emission undoubtedly originates close to the Earth, in the inner plasmasphere, with an emission source location no further than 1 R_E from the terrestrial surface (Prognoz–10 data showed that the source of SANE is located at the geocentrical distance between 1.1–1.3 R/R_E, Kurilchik et al., [1992b]). Thus, the observed dependence of the SANE flux density on distance indicates a beamed character of this emission. The observed dispersion in flux density could be attributed to a number of reasons, e.g. the emission intensity, the time of occurrence, the satellite position within the SANE beam, etc.

Figures 5a and 5b show the distribution of hourly occurrence probabilities of observed SANE for three annual periods with regard to UT (a) and MLT (b). The dependence from UT shows two clear maxima and minima. The main maximum lies between 4 and 13 UT, and a smaller one between 18 and 01 UT. The occurrence probability of SANE with two maxima in UT is an indication of temporal variations of this emission (spatial variations of SANE connected with the terrestrial magnetic dipole diurnal rotation were evidenced in Kurilchik et al. [1992c]). Note that a possible influence due to time selection must be excluded because we have uninterrupted registration and more then 250 SANE events with an exact determined starting time, full duration (in median, about 3–4 hours) and the exact determined time of the end. The hourly probability of the SANE occurrence with regard to MLT shows a gradual growth in the night–side sector from 18–20 hours till a relatively sharp decrease after 5 - 6 MLT (see Figure 5b). Most SANE events are observed between 00 and 06 MLT.

Figure 6 shows a histogram of the probability of SANE appearance with regard to geomagnetic latitudes λ_m of the satellite location (the SANE event was taken in consideration if the event as part of it were within a 10 degrees interval, as shown in Figure 6). The main part of the events is observed between the latitudes 30°–70° with a maximum around 50°–60°, the latitude of the main ionospheric trough. The distribution of the second maximum of Figure 5a with regard to UT (shaded part) is also shown. These events evidently show a clustering to lower latitudes with a maximum between 30°–50°. Remember that the latitudinal width of the individual events here may often be as small as 1°–3°. This is a remarkable peculiarity of the majority of SANE events observed at the time of the second maximum of the UT distribution (see also Figure 3b).

The periodicity of the appearance of SANE with regard to UT demonstrates a dependence on the diurnal rotation of the terrestrial magnetic dipole. Figure 7 shows the probability of the SANE occurrence as a function of the geographic longitude. The maximum of the

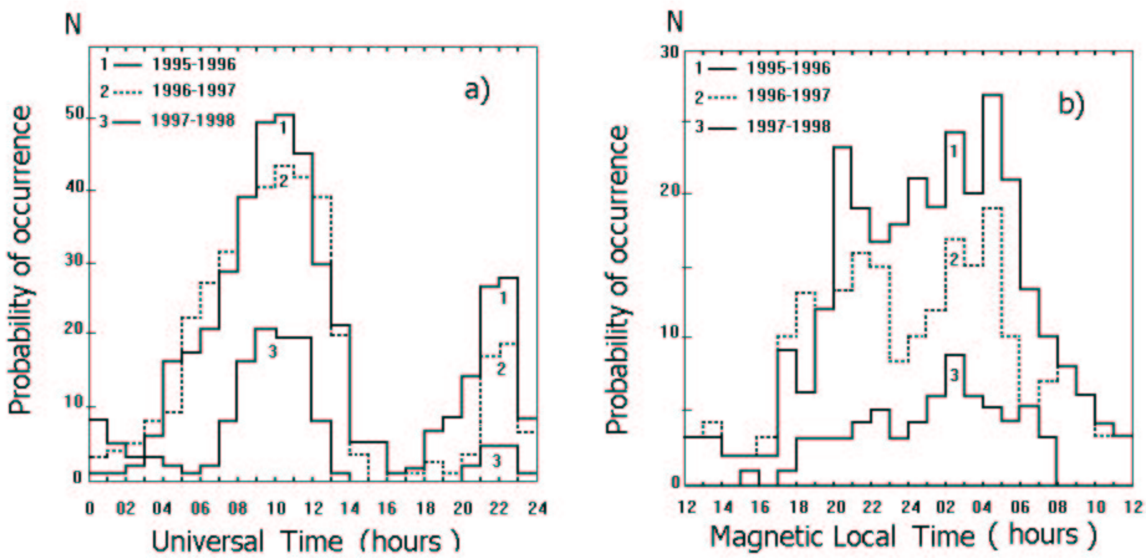

Figure 5: The distribution of the probability of SANE appearance (a) in Universal Time (UT) and (b) in Magnetic Local Time (MLT).

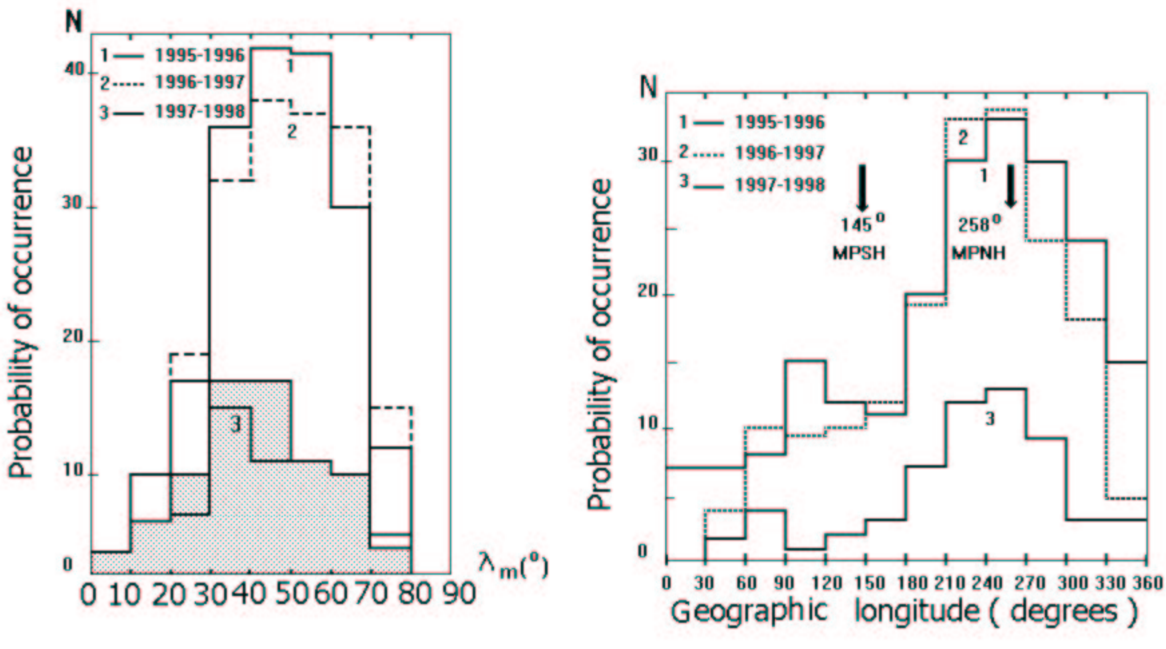

Figure 6: The probability of SANE occurrence as a function of (a) the magnetic latitude and (b) the geographic longitude.

distribution lies at (or close to) the position of the geographic meridian of the magnetic pole of the Northern hemisphere (MPNH, 76°N, 289°E), i.e. the main SANE events are clustered around the satellite position at this meridian $\pm 75°$ (±5 hours of time).

MPNH is localized at the midnight meridian about 06:40 UT. But more detailed statistics show that the maximum of the appearance of SANE manifests itself at 9–10 hours UT (see Figure 5a). Thus the maximum activation of SANE occurs when the meridian of MPNH is positioned in the morning part of the night–side sector of the magnetosphere. The second observed and smaller maximum (see Figure 7) corresponds to the satellite location in the vicinity of the meridian of the magnetic pole of the Southern hemisphere (MPSH).

3 Discussion and conclusion

Despite partial MLTs overlapping the excitation regions of AKR (15 - 21 MLT) and SANE (19 - 08 MLT) in the evening–night sector, no direct relation exists between both emissions. More than half of the SANE events were registered without any observation of AKR at this time. When SANE and AKR were observed simultaneously no correlation of these emissions (intensity, variations in time and so on) does exist. Apparently, SANE is not AKR or high frequency harmonics of AKR.

As a summary we note the following main features of SANE which exhibit distinct differences with regard to AKR: 1) high frequency of emission, 2) comparatively low and limited power flux density, 3) specific smooth background or, more often, impulsive ('forest–like') image with slow variable amplitudes of the impulses, 4) the appearance is predominantly at 0–6 hours MLT, 5) a well established beaming, 6) a well pronounced periodicity of appearance in time (UT), connected with the rotation of the terrestrial magnetic dipole. To clarify the picture regarding propagation of SANE Figure 7 shows the registration of SANE in coordinates MLT versus magnetic latitude λ_m. SANE events are divided into those observed close to the Earth (at distances less than the specific radius of the day-side magnetospheric boundary in a plane perpendicular to the direction to the Sun, that is, 12 R_E, black segments of orbit) and those far away from the Earth (12–32 R_E, red segments of orbit). These figures demonstrate that SANE propagates far away from the Earth into the night–side of the terrestrial magnetosphere and is more pronounced in its morning sector.

The state of Solar activity certainly has an influence on the SANE appearance. Figure 8 demonstrates the character of the gradual suppression of this emission with the increase of Solar activity. This is an important fact studying the mechanism of SANE and other "continuum" emissions (the equatorial continuum below 100 kHz [Brown, 1973] and the kilometric continuum recently discovered by Geotail [Hashimoto et al., 1999b]). The maxima of SANE events at around September of 1995, 1996 and 1997 (Figure 8) are due to the fact that the satellite orbit location at this time was in the morning part of the night–side sector of the magnetosphere (see Figure 7).

We present the main observed peculiarities of high frequency subauroral continuum emission without a discussion of the mechanism of its origin, which will be investigated in

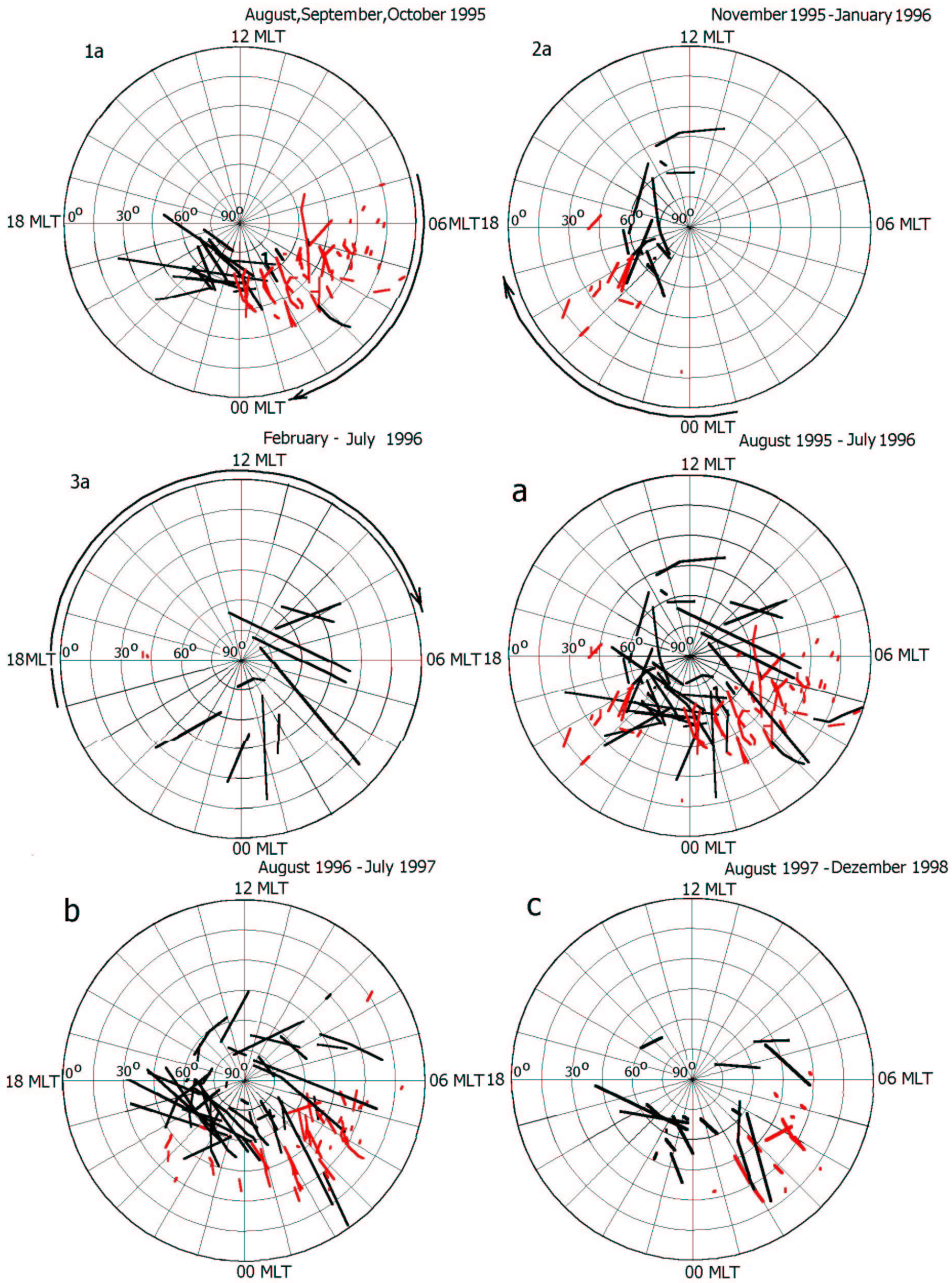

Figure 7: Three periods of the SANE observations (a, b, c) in the coordinates magnetic latitude λ_m - MLT are presented (black segments registrations at distance less than $R/R_E = 12$, red segments $12 \leq R/R_E \leq 32$). The first three figures (1a, 2a, 3a) show part of the period a) at the position of the satellite apogee indicated by black curved arrows.

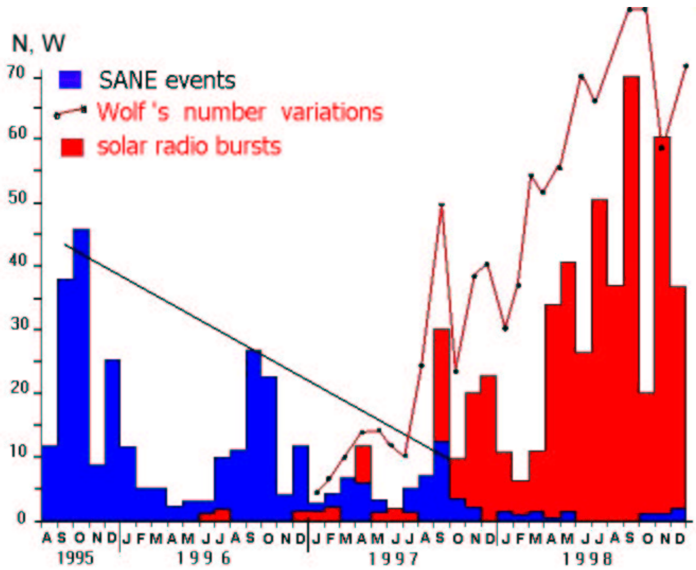

Figure 8: The monthly number of SANE events and Solar kilometric radio bursts observed by INT–1 satellite in 1995–1998. The increase of Wolf's number of Solar activity in 1997–1998 also is presented.

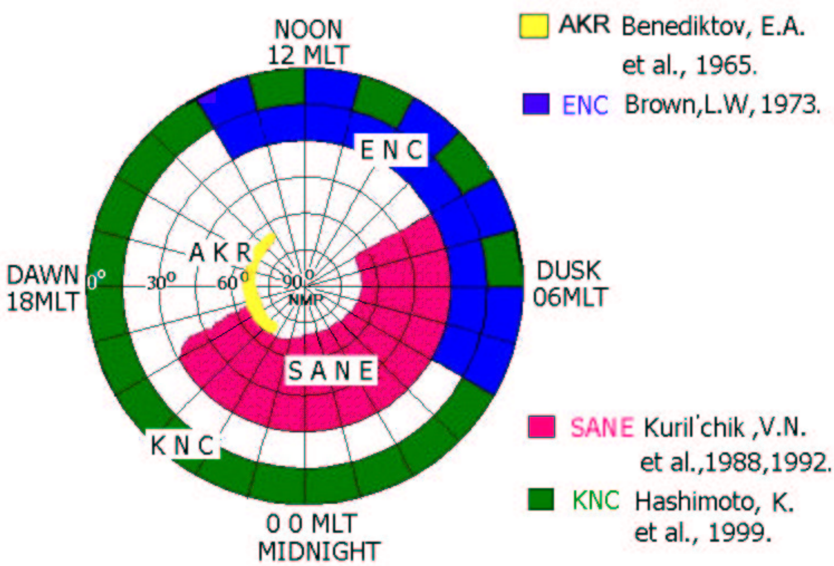

Figure 9: The Northern magnetic hemisphere presentation of the most powerful escaping terrestrial radio emissions. For AKR a region of origin is indicated, for all "continuum" (equatorial, subauroral and kilometric) emissions the regions of their propagation out of the magnetosphere are shown.

other future studies. Figure 9 presents the actual situation with regard to different escaping radio emissions from the terrestrial magnetosphere in the Northern hemisphere (in the Southern hemisphere the distribution should be almost symmetrical).

Acknowledgements: V. Kuril'chik thanks the Austrian Academy of Sciences for financial support during his several visits to Graz (Austria).

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